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Science and Man Symposium

NATURE, MAN AND PESTICIDES

The Science and Man Symposia were held on three evenings during the Congress. Each was designed to explore an important biological problem that besets man and to show how biological knowledge can assist in the solution of the problem.

The symposium, Nature, Man and Pesticides was organized for the Congress by Dr. I. L. Baldwin, who also chaired the session.

NATURE, MAN AND PESTICIDES

OPENING REMARKS

I. L. Baldwin
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I regard it as a high honor to be asked to serve as moderator for the symposium this evening. I also regard it as a great responsibility. We are dealing tonight with a topic of wide interest and deep significance. It is a subject on which the people of the world properly look to the biologist for thorough analysis and sound judgment.

Since the dawn of civilization, man has been engaged in a relentless drive to alter the environment to suit his purposes. The rapid growth in the population indicates that the alterations of the environment have encouraged rather than discouraged the propagation of the species. However, we have often been guilty of practices that may best be described as penny-wise and pound-foolish. May I cite the example of the drive to increase agricultural production by practices which have resulted in massive soil erosion. Practices which result in increased production for a few years but at the cost of the loss of the soil itself have not served man's own selfish interests.

Man has nurtured with great care certain species of plant and animal life which serve his economic or aesthetic needs. Man has attacked with great vigor other species which have interfered with his health, comfort or welfare. However, the large majority of the many species of plant and animal life have been ignored by all but a small proportion of the human population. Fortunately, there is a growing concern, coupled with positive action, for the preservation of all forms of plant and animal life. This effort to preserve our wildlife is too late to save some species, and too little to save others, but an encouraging start is being made. Undoubtedly mankind's own self-interests have suffered in the past, and are still suffering, because of his callous disregard of the damage he does to other species of plant and animal life.

History records that human society has encountered many difficulties in adapting itself to changes brought on by the advancement of technology. During the last two decades the expansion of scientific endeavors and the consequent increase in the accumulation of knowledge has been phenomenal. Technology has quickly translated this new knowledge into materials and procedures for use by society. Undoubtedly every major technological advance has brought the promise of great benefits to mankind and at the same time has brought with it certain dangers and hazards.

A few months ago there was celebrated the twentieth anniversary of the first controlled release of nuclear energy. The story of this dramatic development has been told and retold throughout the world. For ages man has relentlessly sought sources of energy to relieve himself of the drudgery of hard manual labor and to make life more rewarding and useful. The demonstration of the controlled release of nuclear energy for the first time brought the promise of an adequate supply of mechanical and electrical energy to meet world needs for the indefinite future.

But this mastery of nuclear energy also has brought the fear of total devastation by the use of nuclear energy in war. It also brought the danger of accidental radiation damage, and of radiation fallout from the testing of nuclear weapons. Although the dangers are greater in some areas of the world than in others, no people on the face of the earth can feel free from these hazards.

Contemporary with the first demonstration of the controlled release of nuclear energy was the commercial development of three chemicals. These three chemicals have influenced our lives far more intimately during the last twenty years than has the controlled release of nuclear energy. I refer to:

1. Penicillin. This was the first and probably the most important of the rapidly expanding group of infectious disease antagonists -- the antibiotics.

2. DDT. This was the first representative of a powerful new class of insecticides, and twenty years later it is still the standard by which newer insecticides are measured.

3. 2-4-D. This was the first and is still the most important of a significant group of selective plant growth regulators which are often used as herbicides.

These chemicals and others of the same types represent only a small part of the chemical revolution which has completely changed our way of life during the last two decades. Let me remind you of the plastics which package our foods and clothing, ornament our homes, grace our dining tables, provide structural strength for our furniture, boats and automobiles, and furnish the raw materials for the synthetic fibers we all use as a matter of course in our present day clothing. Think of the synthetic detergents which have replaced soap in our kitchens and laundries. Consider the new therapeutic drugs which now work wonders in the treatment of both physical and mental illness. Remember the vitamin pill that you swallowed this morning and the vitamin-enriched bread, milk and cereal which you had for breakfast.

One could continue, for some time, listing the chemicals, now commonly accepted as part of our daily life, which were unknown 25 years ago. In fact, most of the words were not in the dictionary in that day.

Each of these new chemicals has gained wide acceptance because it made an important contribution to man's health, comfort, convenience and wealth. But the valuable contributions of each of these new chemicals have not been without cost, both direct and indirect, visible and invisible. The direct and visible costs have been accepted without question because the direct and visible benefits so far outweigh the direct and visible costs.

We are concerned this evening with the pesticides, particularly with the newer synthetic pesticides, and their relations to the welfare of man and nature, but just as appropriately similar discussions might deal with the new therapeutic agents, the synthetic detergents or other new products of the chemical revolution.

With the continuing use of these new pesticides, the public is beginning to recognize some indirect and previously hidden costs. Unfortunately knowledge of the extent and significance of these indirect costs is still fragmentary. Basic knowledge of the interactions of various forms of life on each other is lacking in sufficient detail to enable the scientist to predict with accuracy all of the indirect effects of the use of these new pesticides on the sum total of living organisms, plant and animal, large and small.

Where knowledge is lacking, opinions occupy the field.

It is relatively easy to determine whether insects have been killed on a field which has been sprayed with a given formulation of a known insecticide at a known rate of application. It is far from easy to determine whether wild animals, birds, fish and mammals, have been killed or their reproductive powers impaired by the insecticide which was used on the field. The complex food chains existing in nature render the problem all the more difficult. Nor is it easy to assess all of the possible effects on human health and well-being.

Certainly, the use of these new pesticides has been a very important factor in enabling modern agriculture to achieve its tremendous increases in productivity.

Certainly, the use of these new pesticides in various areas of the world has proven of inestimable value in breaking the chain of disease transmission and in saving millions of lives.

Certainly, these new pesticides are poisonous to humans and there has been accidental loss of human life due to their use.

Certainly, many fish, birds, mammals and other animals have been accidentally poisoned by the use of these newer pesticides.

Each of us has differing degrees of knowledge as to the extent of the benefits and the damages resulting from the use of these pesticides. Each of us has differing degrees of interest in public health, in agricultural production and in wildlife. And each of us makes differing judgments as to the values of each benefit and damage.

The lack of sufficient research data on all of the effects of the use of the new pesticides leaves the field open to speculation and leads to controversy. The differing value judgments which each of us place on various items add further fuel to the fires of the controversy.

Within the limits of the time available, our symposium this evening has been designed

1. to bring you a summation of the facts which are available in this broad field,

2. to present considered opinions of the significance of the facts which are available, and

3. to give an opportunity for the expression of value judgments in this field.

MAN, FOOD, AND INSECTS AS AN ECOLOGICAL PROBLEM

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Many people have a very strong tendency to consider mankind and its culture as something distinct from nature and natural events; and to those it must come as a rather startling experience whenever they find that they are, after all, linked to other beings, plants and animals, and to the rules of nature to such an extent that they are more a part of than rulers over the world.

Many a person lives most of the time in an environment which is, in most of its aspects, so very much man-made that he no longer realizes that through the boundaries of this environment he is connected with the land, air and waters and the inhabitants thereof. He gets all he wants from neighborhood shops and does not stop to wonder where his food comes from and may not realize that it has to be produced in an environment which in no respect resembles his air-conditioned home, but where the full force of nature's vicissitudes affects the basis of man's food chain. There is so much between the primary production of his food and the consumer that the quite violent oscillations in production are damped by the time his meal comes to the table.

This situation has developed gradually and locally. But the consequent attitude of mind has become dominant among our political and economic leaders. It has led to a situation which is worrying an ever-increasing number of people who have less than complete faith in man's dominating powers.

I want to try and indicate briefly the relation between man and nature from an ecological viewpoint, to trace the way we have come, and to indicate a future course along which we may continue to develop our cultural heritage without, partly unwittingly, destroying our own habitat.

When man was still a hunter and a food gatherer, he did not influence his environment to any greater degree than has any other fairly large mammal. The first important ecological changes occurred when he cleared areas for agriculture, however primitive this may have been from our present point of view.

Of the innumerable numbers of insect species which were to be found in the neighborhood of such agricultural areas, a certain number found the change advantageous. The microclimate may have been more favorable, or certain of their enemies were less abundant there, but certainly it offered an excellent opportunity for reproduction for those which either used the cultivated plant as an oviposition site, or needed this plant as food before reproduction could take place.

Not only did the farmer grow a number of plants together in one place, but he also started selection on a purely empirical basis. It must have come as an unexpected and exhilarating experience that yields could be improved for the next season's crop by taking seed from superior plants rather than taking just a random sample. Selection must soon have become a matter of primary interest to the more observant and intelligent of our forefathers.

But not only humans profited from this activity. Again, also some insects reacted favorably. Larger seeds and more of them, bigger fruits, longer periods of growth, yearly repeated yields, either in the same place or somewhere close at hand, reduced mortality and increased net reproduction rates for a certain number of insects and other animals.

In this gradual process of improving farming techniques, which of course is still going on, we must distinguish between two different principles which underlie the excessive multiplication of insects and which can be distinguished by the names biocoenological and physiological causes: physiological pertaining only to the food of the insects; biocoenological to all other environmental factors.

Biocoenological. A great number of specimens of one plant species, often of the same age, increases the reproductive rate of a number of species of phytophagous insects because there is abundance of available food and oviposition sites. The microclimate is changed and may be more favorable. Through destruction of other plants in the neighborhood the predators and parasites lack alternative preys and hosts, some of which may be convenient or necessary for them.

There are, of course, quite a number of monophagous parasites. But in the complex biocoenosis there are also a considerable number which need more than one species of host to complete their life cycle. For predators this may be more the rule than the exception. But the alternative prey of the host may not feed on the same plant as does the primary prey. Its absence in the monoculture can make it difficult for the enemy to keep its density at a sufficiently high level to influence the host density to a degree which has quantitative importance for the farmer.

There are quite a number of parasites of which the adult feeds only on the body fluids of the host specimen in which they have deposited their eggs. But others need flowers for their food supply. Weed destruction deprives these parasites of a food source and thus reduces their importance.

Then there are the physiological causes. By selecting for greater production many varieties have been created which are more attractive to insects than were the original species, or are less resistant to their attack. In addition, cultural measures may increase the attractiveness of the plant or increase the food value for the insect.

Just one example may illustrate the principle. The Tenthredinid *Hoplocampa testudinea* (Klug), the apple sawfly, lays its eggs in the flowers of the apple trees. The newly hatched larva feeds under the skin of the first apple, then seeks a second in which it tunnels down to the developing seeds. It feeds on them and then must go to a third or even fourth apple before it is full grown. On an apple tree in its natural state, and even in a neglected orchard, the young larva may have difficulty in finding a second and third apple in which to develop. From one mixed bud only one or two flowers may develop. Others may be destroyed at an earlier stage by other insects, and not all may be successfully pollinated. Besides, we will often find alternating years of abundant and scanty flowering. Even if in one year a certain number of larvae succeed in developing, next year there will be little chance of completing the life cycle since, while searching for the next apple, chances of destruction of the larva are very great.

How different in a well-treated orchard, where indeed the sawfly might think--could it think--that the farmer particularly wanted to increase the numbers of them. Yearly abundant flowers, with a very high percentage of them pollinated, in close proximity, and each developing into the necessary apple--this is indeed what we would strive to achieve if we wanted to increase the numbers of Hoplocampa.

The application of fertilizer, particularly nitrogen, stimulates the growth of many crops. It has been shown that certain mites produce nearly twice as many eggs when fed on leaves which have a high nitrogen content, than when fed on leaves from trees which did not receive heavy nitrogen fertilization. With five or more generations of mites per year, this makes an enormous difference in the possibilities of a build-up of damaging populations.

These physiologically favorable circumstances produce a higher natality; the biocoenological changes reduce the mortality rate. Together, and in complicated interplay, they produce our economic entomological problems.

Not all economically important insects belong to this group. Some depend upon the opposite, the unhealthy plant, for their multiplication. This is because we can roughly distinguish between two groups of destructive insects. They have a different significance in the biocoenosis and can, in teleological terminology, be called controllers and destructors.

The first group, the controllers, react upon abundant and good quality food by increasing the amount consumed, producing more progeny and, in general, counteract the plus phenomenon of the plant with a minus factor from the plant's point of view.

Their role in nature can be described as a brake upon the development of a plant. It is a phenomenon much discussed in the population dynamics of animals and which, certainly, is one of the principles which is basic to all biocommunities.

The other group prefers weaker plants for food. Typical examples of this group are the many bark beetles and woodboring insects, which can only live in trees with reduced sap flow. It may be that the soil is not adequate for the plant, the climate not sufficiently favorable, or the weather unfavorable for too long a time. The tree may be mechanically damaged by other insects, or a fungus disease may have attacked the plant and thus reduced its vigor so that the secondary insects proceed to finish it off.

Among insects these destructors, which in nature serve to eliminate the weaklings, may not be so common as the controllers, but they certainly occur frequently in natural communities.

In cultivated plants we will meet both as pests. Keeping crops healthy to reduce insect damage only protects against the second group of plant feeders. Healthy plants, on the contrary, are particularly attractive to the first group. In general, we must come to the conclusion that insect abundance is not an unfortunate coincidence, but an absolute ecological necessity.

It still remains to be investigated for many species in detail which factors have contributed to their abundance. Such knowledge will form an important basis for future work.

Now, once the superabundance of insects has been noted, control measures can be developed. With our distinction between biocoenological and physiological causes in mind, we can classify the control measures on this basis. From the biocoenological point of view, the first thing to do would be to abandon the monoculture of crops. This practice may be possible in private gardens, but the amount of labor involved does not make it a practical proposition in developed or developing agriculture such as we need at the present time. But leaving uncultivated strips around fields may be more profitable than is generally believed.

To a certain extent it might be applied in forestry without too great an economic loss, where a mixed stand can reduce the attack of certain insects, and may even do so to a sufficient degree to make it worthwhile.

Secondly, there is the importation of parasites and predators, or stimulation of those already present. It is a practical proposition and has met with astounding success in a number of cases in widely different parts of the world. It can be recorded as one of the major successes of a scientific approach to a practical problem.

From the physiological standpoint we can try to change the plant by the introduction of resistance factors through crossbreeding. Quite a number of attempts have been made and, in several cases, the efforts were crowned by success. It is a laborious road to take because man is extraordinarily finicky about his food. Such irrelevant qualities as, for instance, the color in potatoes, are essential for the market value. To combine all required qualities in the new hybrid, adapted to local tastes, is no easy matter.

But once the right combination of factors has been found and vegetative propagation or controlled pollination can be practiced, we would seem to be safe for a considerable time--safe, as long as no adaptation of the insect to the new situation occurs. As far as that is concerned, the entomologist has an easier life than the phytopathologist, because fungi and bacteria are much quicker in adaptation than are insects. But in view of our experience with insects and their development of resistance to insecticudes, we cannot rest assured that no adaptation will take place.

Finally, there are the fertilizers. They are being applied for plant nutrition. We know now that this practice may also improve the nutritional value of the plant for certain arthropods. The time has come to reinvestigate the fertilization program with a view toward trying to increase the necessary growth of the plant without unduly favoring the phytophagous insect. This will be a very difficult task and success is very doubtful. But at least we must know what can be done along this line of inquiry.

Then, of course, there are the large group of control measures which do not take into consideration the reasons for the presence of the pest but accepts its presence and attempts to reduce the numbers. In principle, one can say that in these methods we do not try merely to reduce the numbers but that the final aim, at least in theory, is total eradication.

This is true for chemical control, or the introduction of a poison into the environment; for the use of attractants whereby the insects, or one of the sexes, are lured to a place where they can be easily destroyed, or the introduction of sterilized males which compete with the normal ones. By this last method it has been possible to reduce the numbers of insects to below the minimum survival density, so that they have been locally eliminated.

Different treatments have different goals. A perfect biological control is one in which phytophagous insects and enemies are both permanently present at low levels. Low, here, means a density at which the damage to the plant is below economic significance.

What is a reasonable level of insect damage depends upon your viewpoint. To give a few examples: several percent reduction in yield of a potato field may be a small loss compared with the variation in production due to uncontrollable weather factors.

A small blemish due to the feeding of Capsid bug on fruit gives no measurable loss of weight of the crop but does bring down the price considerably. Hothouse flowers with slight discolorations are practically unsaleable.

The attitude of various entomologists towards insect control therefore may be fundamentally different and, to some extent, depends on the kind of plant or insect which is their main concern. For some, a low population which is permanently present, but which does not explode to outbreaks with large numbers because there are sufficient elements in the biocoenosis to counteract such an increase, is a happy situation. Others, on the other hand, are not satisfied until the insect is completely annihilated.

Calling upon the aid of supernatural forces to protect crops must be as old as agriculture itself. It was the first method of insect control. Chemical control then followed. Biological control, as a scientifically based project with a specific purpose, began about 70 years ago. Since World War II, the use of chemical control has been increasing at an astounding rate.

The reasons for the present neglect of the ecological standpoint are obvious. Chemical control is a quick solution for what can be an acute problem. It is a thing which can be done individually and locally by a grower, independent of others and of other agricultural activities. Its results are frequently immediate and spectacular.

I will give just one example of a near perfect chemical control. The Pear Bud Weevil (Anthonomus cinctus) aestivates on or near pear trees, emerges in the first week of September, and oviposits in the mixed buds. The larvae develop during the winter and the pupae are formed in the hollowed buds. The adults emerge in May, aestivate in the immediate proximity, and again emerge in September. There is very slow spread from tree to tree.

One application of DDT, as soon as the first feeding punctures in the buds are found in September, is sufficient to clear the whole orchard of this pest for a great number of years. At that time in September few pears have not yet been harvested and predator destruction is very limited. Without control, the weevil may destroy more than half the pear crop. The use of a chemical is an excellent method of control from every point of view.

The great success of chemical control, backed up by the commerical interests of the manufacturers of these products, has induced many entomologists to develop methods for perfecting techniques based on biological knowledge of the pest to be controlled; as a result, studies based on the ecological point of view have received less attention.

There are, however, some disadvantages to this mode of approach and they become more apparent as the use of insecticides has increased:

1. No pest is ever quite without its natural enemies. They may be few and far between, but they will seek out concentrations of their prey or hosts and feast upon them. By applying insecticides these last remnants of biological control are further eliminated. The few phytophagous insects generally left over from the chemical treatment will be able to develop freely, particularly since enemies which escaped the chemical will either soon die from lack of food or wander off in search of better hunting grounds.

The phytophagous insect has a good start and, in the excellent conditions provided by the farmer and often freed from cumbersome competitors, will increase at a greater speed than ever before.

This is certainly a valid explanation of many "flare-ups" noticed in the field after chemical control. Aphids and spider-mites are notorious for this phenomenon.

Some of my audience may have wondered why I have not yet used the simple expression of "upsetting the natural balance" of populations. The reason is simple. There is no balance, but only unbalance. There is never for one moment a static equilibrium, but a continuous change of numbers which is related to intrinsic and extrinsic factors. And it is not natural, at least in any cultivated part of the world, because that would imply non-interference by man. In the cultivated field we, therefore, have an unnatural unbalance, and that is not a very useful expression.

2. The second difficulty encountered by chemical control is the development of resistance. From 1906 onwards, entomologists have known that resistance develops, first in scale insects on Citrus in California, then in the Codling Moth in fruit-growing areas more to the east and, gradually, in more than one hundred insect species of agricultural and medical importance all over the world.

In the beginning, even many entomologists did not take this phenomenon very seriously and only in the last 15 years has its existence been generally accepted. Ways of combatting the build-up of resistance have been suggested, such as the use of different insecticides or the introduction of non-resistant populations into resistant ones or using insecticides with opposed selection pressure so that insects resistant to compound A are particularly susceptible to compound B. Theoretically, this last is a more elegant method; but, up to now, the chemicals for a practical application in the field have not been found.

3. There is one still insufficiently understood and unpleasant side to the use of insecticides and that is the stimulating effect which they sometimes can display. Sublethal doses of DDT may increase egg production in grain weevils and spider-mites.

Applications of insecticides and fungicides which leave dry residues enhance the development of scale insects and spider-mites. The physiological basis for both of these phenomena is, as far as I am aware, still unknown.

This leaves us in the rather unhappy situation that the easiest, and often the cheapest, way of controlling insects is already beginning to lose its attractiveness because we have to increase continuously the frequency and the concentration of our applications. And even that will not be sufficient as the number of resistant species increases and resistance spreads further in those areas where it has already developed.

Furthermore, as we go on, insecticides will accumulate in places where we do not want them and they are already threatening the existence of many species of mammals, birds, fish and others, which no one wants to eliminate.

After the admirable summary of facts to be found in many places, and particularly in Miss Carson's "Silent Spring," the terrible consequences of too free use of insecticides need not be treated extensively here.

Now, how can we extract ourselves from this slowly tightening noose into which we have put our heads?

It is obvious that chemical control can only be considered as a temporary reduction of the number--very effective for the time being and without the extensive application of which the food situation in the world would be considerably worse than it is.

But we cannot continue to work on this plan and must head in another direction. This is being done already in several places and in several fields. Integrated control aims at a combination of biological and chemical methods.

One of the first to get applicable results was Pickett and his team in Nova Scotia in orchards. Elsewhere, similar ideas are being worked out. Progress is slow but, in spite of the largely empirical approach, we are getting somewhere.

What we need is a general change of attitude. We must come to realize that we must live with insects--a by-no-means-peaceful coexistence--and that they shall always have a share of our food. We may be able to exterminate a few of them, without killing too many other animals and without poisoning our own habitat, but we cannot kill them all. We must try and establish a biological agriculture, and this can be done by combining <u>all</u> forces in our favor and not concentrating on just one.

Because, if we seek varieties which are not too attractive for the insects, if we do not make them too attractive by our fertilizing program, if we allow the right kind of other plants to grow near our fields, and if we introduce or help along the entomophagous insects instead of killing them off, then, with the help of insecticides as specific to the pest as possible to reduce occasional outbreaks which will surely occur every now and then, we could produce food in an economic way at the sufficiently high level which is so urgently needed.

If we think and work along these lines we may escape the doom which is threatening ahead.

Only then will we be able to continue to live in a world worth living in, and be, ourselves, worthy of the self-adopted name Homo sapiens--the species which distinguishes itself from the other animals by the excessive development of certain parts of its central nervous system.

Let us try to make the best use of our intellect and think not of ourselves alone, but look ahead for the sake of the generations to come.

OPPORTUNITIES FOR THE DEVELOPMENT OF SPECIFIC METHODS OF INSECT CONTROL

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Today, it is possible to control the vectors of malaria, typhus, plague, and virtually every other major disease spread by arthropods. Devastating outbreaks of most insect pests that attack crops, forests, and livestock can be prevented. Man can preserve and protect his stored foods, his clothing, and his home from the many insect pests that continue their destruction, even after the agricultural products have been harvested and processed. Various methods of insect control have been developed to make such outstanding progress possible. However, chemicals provide the means for dealing with most of these insect problems.

Research for a century contributed to our basic knowledge of arthropod pests and disease vectors, but most of the progress in controlling them has been made during the last two decades. During this period we have seen the development and use of DDT, toxaphene, methoxychlor, chlordane, lindane, dieldrin, heptachlor, parathion, malathion, allethrin, piperonyl butoxide, coumaphos (co-ral), carbaryl (Sevin), and many other highly effective insecticides. The amounts of insecticide used in the United States increased several fold in the two decades from 1943 to 1963. The increase in the use of insecticides in recent years has led to problems that are of major concern to the public. After making an exhaustive study of the problem, the President's Science Advisory Committee on May 15, 1963, issued a report entitled, "Use of Pesticides." The report identifies a number of hazards and potential risks associated with the use of insecticides. The report also makes certain recommendations for correcting or alleviating these problems. With regard to research, it recommends that investigations be intensified on more selective and less persistent pest control chemicals, on more selective chemicals and ways to employ them, and on nonchemical control methods.

Entomologists and associated scientists have always recognized that insecticides create potential hazards to other forms of life. Certainly, the arsenicals, one of the oldest classes of insecticides, were not specific in effect on destructive insects. This class of compounds creates many of the same types of hazards that are causing most concern in connection with the use of the newer organic insecticides. Likewise, nicotine sulphate, hydrogen cyanide, thallium, sodium fluoride, carbon disulphide, and other older insecticides create special hazards to man and animals. However the extensive use of a wide variety of new organic compounds has added to the complexity of the hazard problem.

Scientists have not been unresponsive to the need for research to avoid or minimize the hazards that are associated with the use of pesticides. When the importance of insecticide residues in meat and milk was evident as early as 1949, efforts were made immediately through cooperative research by industry, the State Agricultural Experiment Stations, and the Department of Agriculture to find less persistent insecticides which would not accumulate in animal tissues. When new insect problems emerged because of upsets in the balance of beneficial and destructive insects, entomologists began research on insecticides or methods of use which were more selective in their effect on target species. When the chain effect of TDE on fish and fish-eating birds was recognized in Clear Lake, California, entomologists began investigating how they might control the gnats in Clear Lake by other materials and methods of use that would not pose this danger to wildlife. Research on the controversial program for control of the fire ant, Solenopsis giminata (F.), was concentrated on more specific and less hazardous measures and led to the development of a new bait treatment which greatly minimizes hazards to wildlife. The problems that confronted the scientists were the wide range of pesticides, the many uses involved, and their inability to fully investigate all of the diverse aspects encountered.

In spite of the limitations in research resources, much progress has been made in the safer use of insecticides. As research continues, we can expect substantial progress in the development of conventional types of insecticides and methods of use which will further reduce hazards to other forms of life. Research should be intensified to achieve this objective, but it seems highly desirable to devote more effort on controlling insects by alternate ways that are specific in their effect on the target species and thus completely avoid or greatly minimize side effects. Such alternate methods might be used alone or as supplements to conventional chemical control procedures.

The conventional types of insecticides will be needed for some time to come so as to meet many of our insect problems. Insects still take a toll amounting to billions of dollars each year. They are a continuing threat to our health and comfort. It will not be possible to develop specific chemicals or specific control measures for all of the thousands of harmful insects. It seems important, however, that we make a full study of the several hundred key insect species responsible for the use of perhaps 90 percent of the insecticides employed today, with a view to the development of specific methods of control for these key species. The achievement of such an objective will require a major research effort. Unlike research on broad spectrum insecticides, research on ways to control a particular insect requires a highly individual approach. It becomes obvious, therefore, that the nation's research resources must be increased substantially if we are to make rapid progress in the attainment of this objective.

The Entomology Research Division has during the past 8 years reoriented its research efforts to explore to the maximum extent possible various nonchemical and specific chemical approaches to insect control. During this period approximately half the research effort formerly devoted to conventional insecticides has been shifted to research on insect pathogens, insect parasites, varietal control, specific insect attractants, and the use of insects for their own destruction. Most of these ways to control insects have been considered by scientists in the past. In general, however, they have not provided many solutions. For every success by a nonchemical or specific chemical procedure, there have been 10 successes by the conventional insecticide approach. Nevertheless, the additional basic information available today, the latest advances in technology, and the recently developed techniques give us much better opportunities to develop new approaches to insect control than those we had in the past.

Biological Control Agents

Parasites and Predators -

Insect parasites and predators, as well as other organisms, prey on destructive insects and play vital roles in keeping the pest populations within reasonable bounds. Their invaluable assistance has long been recognized by entomologists. For a hundred years intensive research has been undertaken to pit insects against insects as a means of control. The importance of establishing and maintaining a good balance between beneficial parasites and predators and the destructive insects on which they live is, therefore, fully appreciated. Making use of this principle is the reason why the search for and importation of parasites and predators is one of the first efforts made to develop ways to control newly introduced pests. Over 650 species of parasites and predators have been introduced from foreign areas. Of these about 150 have become established.

Natural enemies keep populations of many potentially destructive insects at a level that makes them of minor importance. There are important limitations, however, in the practical value of insect parasites and predators as the sole means of insect control. Many native insects may develop high populations when natural upsets occur in the balance between the beneficial and the destructive insect hosts. Such upsets in balance may occur for many reasons, most of which are not too well understood. When such upsets do occur, a generally minor pest can become a pest of major significance, even if the normal balance is restored and the population quickly declines. A second factor that limits the usefulness of natural insect enemies involves introduced pests. When a new insect becomes established in a new environment, most of its natural enemies that have evolved over thousands of years in their native home are left behind. Even though intensive efforts might be made to find and introduce such natural enemies, it is difficult to establish even a reasonably normal complement of specific parasites or predators in the environment. A third condition limits the value of natural enemies. Certain crops may not suffer high losses in yield due to moderate insect populations but the quality of the crop may be severely affected. Corn earworms, Heliothis zea (Boddie), may reduce the yield of corn by less than 5%. This is an important but not a major loss in the production of field corn. However, an infestation level that would reduce yields of sweet corn by 5% would probably mean a reduction in marketable ears by 25 to 50%. Similar situations exist for a wide range of farm products.

In spite of the limitations of parasites and predators, the value of the importation of natural enemies of destructive or potentially destructive insect pests must not be minimized. We have been successful in solving some insect problems by importation of natural enemies. Many other examples of partial success in keeping populations of introduced pests to reasonable levels can be cited, even though supplemental control measures may be necessary.

Without natural biotic agents we could hardly compete with the insects. Thus, these agents are of great value to us and it is important that we protect and utilize them to the maximum extent possible. The value of insect parasites and predators is fully appreciated when large numbers are destroyed by broad spectrum insecticides and normal population levels of the host insects cannot be maintained. Many times insecticides destroy sufficient numbers of beneficial parasites and predators in the environment to give rise to destructive populations of normally minor pests, or the parasite and predator complex of the target species can be so reduced that we must rely on regular spray schedules to protect the crop.

In view of the value and limitations of insect parasites and predators of destructive insects, we might well ask, "What is the future role of such natural biotic agents in meeting insect problems?" Two ways might be suggested to make greater use of such agents. One way is to be more restrictive in the selection and use of insecticides to control insects. Research on the integration of biological and chemical control procedures is receiving more and more attention by entomologists. Such research workers as Pickett (1959), Ripper (1956), and Stern et al. (1959) have made important contributions to this area of research during recent years.

Another way we might utilize natural insect control agents to greater advantage is to mass produce and release at regular intervals enough parasites and predators to achieve adequate control of the destructive pest. This approach to insect control was considered in the past; but, in general, results were disappointing. However, I feel confident that as we learn more about how to mass produce beneficial insects at reasonable costs and how to select and use such mass produced insects more effectively, we will be able to utilize biotic agents with greater success.

Microbial agents -

Insects are subject to diseases caused by various kinds of viruses, bacteria, fungi, protozoa, and other microbial agents. These organisms play vital roles in keeping insect populations at reasonable levels. However, their limitations, as far as the maintenance of a natural biotic balance is concerned, are essentially the same as those of parasites and predators. Thus, we cannot consistently count on these organisms to help solve our insect problems under natural conditions. It is generally agreed by biologists, however, that application of mass produced microbial agents offers one of the more promising and desirable ways to control insects. Insect pathogens are generally highly specific and often affect only one insect or a group of related species. Because of their great promise for insect control, research on insect pathogens has been intensified substantially during the past decade.

The University of California, under the able leadership of E. A. Steinhaus, has placed major emphasis on insect pathology. More and more attention is being given to a study of insect pathogens by investigators at home and abroad. The Entomology Research Division has also intensified its research in this area.

One of the first examples of successful use of an insect pathogen to help control an insect was the use of milky spore disease for controlling the Japanese beetle, *Popillia japonica* Newman, (Dutky, 1963). In recent years several workers in different countries have helped develop *Bacillus thuringiensis* var. *thuringiensis* Berliner for insect control. This disease organism is now registered in the United States for use in control of such insects as the imported cabbage worm, *Pieris rapae* (L.); the tobacco hornworm, *Protoparce sexta* (Johannson); tobacco budworm, *Heliothis virescens* (F.); and the alfalfa caterpillar, *Colias eurytheme* Boisduval. Important progress has been made at our Ankeny, Iowa, laboratory in developing this organism for use in controlling the European corn borer, *Ostrenia nubilalis* (Hubner). Several other organisms are being used or show promise as direct ways to control insects. A polyhedral virus of the alfalfa caterpillar is employed for the control of this pest on alfalfa in California (Thompson and Steinhaus 1950). Encouraging results have been obtained with a polyhedral virus for the control of the cabbage looper, *Trichoplusia ni* (Hubner). The practical use of highly specific pathogens may often hinge on the degree of success that can be achieved in mass producing the insect host. Personnel at the Pink Bollworm Investigations laboratory of the Entomology Research Division at Brownsville, Texas, have developed ways to mass produce the cabbage looper and to grow the virus in the insect host. Workers at this laboratory are also making progress in developing a polyhedral virus for the control of the corn earworm, and the tobacco budworm. Investigators have shown that viruses of other agricultural pests, including forest insects, are highly susceptible to specific viruses. Outstanding progress is being made in the mass culture of many kinds of insects.

With the interest shown by research workers in public, as well as private, institutions, we have reason to believe that in future years insect microbial agents will play an important role in meeting a wide range of insect problems.

Varietal Resistance to Insects

It is well established that through selection we can develop plant varieties resistant to diseases, insects, and other organisms (Painter 1951, Packard and Martin 1952). Through the joint efforts of plant breeders and entomologists, several outstanding successes have been achieved in developing plant varieties resistant to insect attack. Certain varieties of wheat developed recently are virtually immune to the Hessian fly, *Phytophaga destructor* (Say), and millions of acres of such wheat are now grown in this country (Painter et al. 1953). Excellent progress has been made in developing strains of corn that are resistant to the European corn borer (Penny and Dicke 1959). More and more of these insect resistant corn hybrids are being grown to take the place of susceptible strains. We can grow sweet corn varieties that are highly resistant to the corn earworm (Guthrie and Walter 1961). When the spotted alfalfa aphid, *Therioaphis maculata* (Buckton), became established in the United States and threatened the alfalfa industry, certain alfalfa varieties were found to be highly resistant to this aphid (Smith et al. 1958). Entomologists and plant breeders have also developed other varieties that show high resistance to this pest. Additional examples of success in developing crop varieties resistant to insect attack could be cited.

It is unfortunate that the varietal resistance method of insect control has not received more research attention. The method approaches the ideal as an insect control procedure. It obviates any hazard to man or other organisms in the environment. It costs no more to grow suitable resistant varieties than susceptible varieties. Its only disadvantage is the long period of research generally required to find insect resistant germ plasm and to incorporate the character into otherwise suitable varieties. The costly and long term investment in research is the chief reason for the lag in developing this way to meet insect problems. However, a concerted research effort on many crops and many important insect species attacking the crops is long overdue. The public should be willing to make the necessary investment as a long range contribution to the achievement of maximum safety in pest control methods. The success achieved when concerted research efforts were made to develop insect resistant plant varieties suggests that this approach to insect control will prove successful against a wide range of crop pests and could undoubtedly provide a way to lessen damage by external parasites of animals as well.

Insect Attractants

In the past century entomologists, chemists, engineers, and other scientists have devoted much research effort to the evaluation of many kinds of baits, baited traps, light traps, and other ways to attract and destroy insects. In general, results have been disappointing; but there is every reason to believe that insect attractants can provide highly effective and desirable ways to control certain insects. The Entomology Research Division has intensified its research on the attractant approach to insect control during recent years. Some notable successes achieved in the past decade justify our optimistic view that attractants may provide specific ways to control a number of insects and thus avoid or greatly minimize hazards to other forms of life.

When the problem of insecticide resistance in house flies, *Musca domestica* L., became acute in the early 1950's, our Orlando, Florida, laboratory made a concerted effort to investigate attractants for the house fly. This effort led to development of highly effective granular, sweetened fly baits containing small amounts of insecticides.

Investigators of the Division's Hawaii and Mexico City laboratories have placed major emphasis on development of attractants for the control of tropical fruit flies. These research efforts have met with outstanding success. The protein hydrolysate-malathion bait sprays were developed through cooperative efforts of the Entomology Research Division and the University of California, which provided the means for the eradication of the Mediterranean fruit fly, *Ceratitis capitata* (Weidemann), in Florida on two occasions during the past decade (Steiner et al. 1961). Combining hydrolysate and malathion reduced the amount of the insecticide required for control by about 75 percent. The same baits are useful for controlling a number of other tropical fruit fly species.

Further research on attractants for fruit flies by the Division's entomologists and chemists has led to several highly effective male lures for the Mediterranean fruit fly and the melon fly, *Dacus cucurbitae* Coquillett. These lures are of great value as survey tools and may also be of value in control (Hall et al. 1957). For many years methyl eugenol has been known to be a highly effective and specific lure for males of the oriental fruit fly, *Dacus dorsalis* Hendel. Research workers of the Hawaii Fruit Fly Investigations laboratory of the Entomology Research Division have devoted special research efforts to utilization of this lure for oriental fruit fly control. Investigators at this laboratory recently announced eradication of the oriental fruit fly on the Pacific island of Rota by male annihilation, accomplished by using a combined treatment of methyl eugenol and an insecticide. This experiment, carried out with the cooperation of the U. S. Navy and the Trust Territory of the Pacific Islands, may well rank as one of the most outstanding developments in entomology, especially in view of the progress that is being made in the development of sex lures for other species of insects.

For many years chemists of the Entomology Research Division investigated the nature of the powerful male lure produced by virgin females of the gypsy moth, Porthetria dispar (L.). Jacobson et al (1961) reported on the isolation, identification, and synthesis of the chemical substance produced by the female. A related compound, possessing essentially equal attraction for male moths, is now being produced for survey purposes and for possible use in the control of this insect.

Research workers of the U. S. Army at Natick, Massachusetts, isolated from the female of the American cockroach, Periplaneta americana (L.), a substance which possesses unusually high attraction to the males. Jacobson et al. (1963) recently announced the structure of this substance. Investigators at the University of Wisconsin demonstrated the presence of a highly active male attractant in females of the European pine sawfuly, Neodiprion sertifer (Geoffroy). In the past 3 years, the presence of extractable natural male lures, also called pheromones, in females of other insect species has been demonstrated by research workers of the Entomology Research Division. The insects possessing such specific attractants include the pink bollworm, Pectinophora gossypiella (Saunders); southern armyworm, Prodenia eridania (Cramer); tobacco hornworm; Hessian fly; cabbage looper; peach tree borer, Sanninoidea exitiosa (Say); lesser peach tree borer, Synanthedon pictipes (Grota & Robinson); European corn borer; banded cucumber beetle, Diabrotica balteata LeConte; and house fly.

The finding of such natural and highly specific pheromones in many insect species opens an entirely new field of exploration in the effort to develop effective and specific ways to control or eradicate insects. Such substances are extremely active biologically. There is real hope, especially in view of the establishment of the principle of insect eradication by male annihilation, that a concerted program of research in this area will eventually lead to effective and highly specific ways to control some of our major pests.

Other ways to use insect attractants need further exploration. We should reconsider light traps. Engineers and entomologists are obtaining more basic information on the effects of various radiations on insects. Improvements in trap designs are being made. Perhaps of equal significance, entomologists are beginning to fully appreciate the importance of applying control methods against the total insect population in a large area, rather than against small segments of the population. A large-scale light trap experiment is now being conducted by Agricultural Research Service entomologists and engineers in an attempt to control the tobacco hornworm in an area comprising more than 100 square miles. Results from the first 2 years of trapping, with more than 300 light traps involved, show promise.

Other examples of progress in developing attractants can be cited. In fire ant control, the development of a bait that requires only about 4 grams of an insecticide represents an important achievement. Entomologists, chemists, and plant physiologists have joined efforts to determine what elements in a cotton plant are responsible for the attraction of the boll weevil, Anthonomus grandis Boheman, to cotton. They have already found two specific cotton substances that are highly attractive to boll weevils.

The above is only a brief account of the advances in research on insect attractants; however, it should serve to indicate the opportunities afforded by a full investigation of the attractant approach to insect control.

The Use of Insects for Their Own Destruction

Because of the success achieved in eradicating the screw-worm, Cochliomyia hominivorax (Coquerel), from the island of Curacao (Baumhover et al. 1955), and more recently from the Southeastern States, by rearing and releasing sterile males, much interest has been demonstrated in possible adaptation of this technique for the control of other insects or other pest animals. This approach to insect control represents the ultimate in specificity. The principles involved in insect population control were previously discussed (Knipling 1955). In brief, the approach involves the production and sustained release of sexually competitive sterile insects in sufficient numbers to overwhelm the natural population. If the sterile males released are sufficiently numerous, initially, to cause a decline in the natural population, the continued release of sterile males will result in a progressively higher ratio of sterile to fertile insects, until the chances of fertile matings will be nil. The inevitable result will be complete elimination of the natural population.

Several requirements must be met for the sterile male release method to be feasible. A satisfactory method of sterilizing the insect must be developed. Ways to mass produce and release the insects in sufficient numbers to have a marked impact on the reproductive potential of the entire population of normal insects must be developed. The releases must be sustained for a sufficient period of time to achieve the objective.

The screw-worm fly, a major pest of livestock, was the first insect controlled in this manner. However, during the past 8 years the Entomology Research Division has devoted increased research attention to this approach to insect control. Recently, the Division's Hawaii laboratory announced the completion of a successful pilot eradication experiment involving the melon fly on the island of Rota in the Pacific. The experiment was carried out with the cooperation of the U. S. Navy and the Trust Territory of the Pacific Islands. The natural insect population was first reduced by about 75 percent by the use of a bait spray. This treatment was followed by the release of about 8 million sterile melon flies each week on the 33-square-mile island. Within a period of 3-4 months eradication was accomplished.

This is the second important insect eradicated by the sterile-male release method. The melon fly is a multiple mating species, in contrast to the screw-worm, which is monogamous.

The question is often raised as to the role the sterile-male release method may have in the future. We do not know to what extent the method might be employed. However, there is every reason to believe that the method will be of great value in helping control and eradicate a number of important insect species.

The sterile-insect release method has on inherent advantage over all other insect control methods with the possible exception of the mass production and sustained release of large numbers of parasites and predators. Every other control method in use tends to become less and less efficient as the pest population declines. This is one of the main reasons why eradication procedures are generally so difficult. The sterile-male release method, on the other hand, becomes more efficient as the natural population declines. Thus, we have a new technique that is ideally suited to supplement other insect control methods.

Research during the past 5-10 years has shown that most insects can be sexually sterilized by exposure to gamma radiation or certain new chemicals that produce similar sterilizing effects. Research on insect nutrition has greatly increased our knowledge of mass production procedures. More and more basic information is being obtained on the behavior, ecology, and population dynamics of insects.

Sufficient information in these vital areas has been obtained to indicate that the sterile-male release method might prove useful as an aid for the control or eradication of a number of insects, including the Mediterranean fruit fly; oriental fruit; fly Mexican fruit fly, *Anastrepha ludens* (Loew); pink bollworm; boll weevil; tobacco hornworm; codling moth, *Carpocapsa pomonella* (L.); and *Drosophila* spp. fruit flies. There is reason to believe that the method can in time be developed as an important aid in controlling or eradicating many other insect pests and disease carriers in favorable circumstances. I have had a special interest in appraising the potential role that the sterile-male release method might play in eradicating tsetse flies, *Glossina* spp. In spite of the difficulty of rearing tsetse flies in large numbers, the population dynamics of these important insects are such that the method should prove useful for eliminating low level populations. The method should also be useful for eliminating high level populations which have been first reduced by the use of chemicals or other control methods. The development of the sterile-male release method for insect control or eradication requires research on many aspects of entomology that have received only a little research effort in the past. Investigations are essential on behavior of insects, their nutrition and rearing, their ecology and population dynamics, and their dispersion, as well as on methods of inducing sterility.

In addition to release of sterile insects, another utilization of the sterility principle offers opportunities for the future--that of sterilizing the insects in the natural population. The production of sterility in the natural population of insect or vertebrate pests without adversely affecting mating competitiveness will have a far greater impact on the reproductive potential of a pest population than the destruction or removal of the same number of individuals of the population. This is a fundamental principle of population control first advanced by Knipling (1959). The procedure remains to be fully exploited by scientists in the future.

The Entomology Research Division has undertaken a program of exploratory research in this field. Excellent progress has been made, although much additional research will be necessary before the method can be employed for practical insect control. Several chemicals have been found to produce irreversible sterility in insects (LaBrecque 1961). In some insect species sexual behavior or competitiveness is not adversely affected; in others the length of life and competitiveness are substantially reduced; whereas, in still others, such as the house fly and the Mexican fruit fly, males sterilized by one or more of the chemosterilants now available appear to be slightly more competitive than normal males. Chemicals that sterilize insects most effectively are highly reactive and not much is known about their hazards to man or animals. However, they are regarded as potentially of considerable hazard and for this reason practical field tests are being conducted with extreme caution.

For the present, chemosterilants are chiefly of interest in producing sterility in reared insects to be released. For this purpose they will no doubt offer certain advantages over the radiation procedure. However, chemosterilants employed along with specific attractants may in time be found to be effective and safe for sterilizing insects in the natural population.

In conclusion, we have every reason to believe that basic and applied research will provide many opportunities for developing biological and highly specific chemical methods for the control or eradication of many insect pests. Excellent progress has been made during recent years with rather limited investigations in the fields of insect pathology, varietal control, insect attractants, and in the use of the sterile-male procedure. Natural insect parasites and predators provide vital natural forces in limiting insect population increases, and every possible means of utilizing these natural agents to the maximum extent should continue.

In all probability no single procedure will be the best for solving most insect problems. Conventional-type insecticides will continue to play a vital role in insect control for many years to come. However, as research progresses, various alternate methods discussed in this report, as well as other new approaches, will be developed to meet or help meet many major insect problems.

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EFFECT OF PESTICIDES ON HUMAN HEALTH

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Mortality from Pesticides in the United States

In the United States, the death rates associated with accidental poisoning by gases and vapors and by solids and liquids have remained relatively stable since 1939, when the present method of counting was established. There was no significant change in the rate of poisoning when DDT was introduced experimentally in 1942 and commercially in 1946, nor from the introduction of a wide variety of other new pesticides beginning about 1946. The rate for all accidental poisoning in this country for the last 25 years has been about 2 per 100,000 population, a rate only about half that for comparable poisoning reported between 1900 and 1910. The foregoing statements are based on official figures from the National Office of Vital Statistics. As with much of what follows, I have discussed the statistics in detail in a report published in 1960 (8).

In different years, deaths from pesticides have accounted for 7.8% to 12.8% or an average of about 10%, of deaths from all solid and liquid substances. The percentage is not increasing, but, in cities, the proportion tends to be lower -- 4.3% in one study. Fumigants contribute only a very small and relatively constant proportion of deaths caused by gases and vapors. Thus, pesticides cause an annual death rate in the United States of about 1 per 1,000,000 population.

Increases in the use of the newer pesticides, both in absolute tonnage and in relation to the older compounds, have added to their relative importance as causes of mortality. However, at least as late as 1956 and probably at present, over half the deaths associated with pesticides were caused by compounds older than DDT. Furthermore, over half the deaths are in children. These facts suggest that improvement could be made in the record if old poisons were used with the same care as new ones, and if all poisons - old and new - were stored under lock and key and then used in such a way that children could have no significant exposure to them.

The conditions of use may be just as important as the toxicity of a compound in determining its hazard. Aspirin is far less poisonous than parathion; yet it is a more important cause of death because it is so much more widely distributed and so often is stored carelessly. Children have a far greater opportunity to find and swallow a fatal dose of aspirin than any dose of parathion.

Morbidity from Pesticides in the United States

In this country all deaths must be reported, irrespective of their cause. Unfortunately, this is not true for nonfatal illnesses, including those caused by poisoning. Therefore, the number of cases of nonfatal poisoning must be estimated from the ratio of nonfatal to fatal cases found in special studies. There were from 25 to 115 nonfatal cases of poisoning for each fatal case in different years during 8 years of experience in one major city. Records of poison control centers frequently reveal a ratio much greater than 100 to 1, but less than 10% of the cases reported to them are hospitalized, and as many as 70% show no symptoms of illness. The most accurate estimate at this time, then, is that only one of about 100 cases of significant poisoning is fatal.

In most instances poisoning in man is clinically similar to poisoning in experimental animals. Animal studies have provided much valuable information, but have their limitations. The common laboratory animals are more susceptible than man to poisoning with some compounds, but less susceptible with others. The dynamics of storage may be different in animals and man.

Time will not permit us to explore the clinical aspects of poisoning by pesticides, but we should note that at least 49 different materials have produced human cases. This number would be larger if the individual compounds of arsenic, for example, were counted separately.

Although the effect of both single and repeated doses of pesticides on people is rather well known, there can be no *a priori* assurance that at least a few people will not respond to a particular chemical with a pattern of illness different from that previously established. It is conceivable that there may be long-term effects in man even when it is impossible to demonstrate them in experimental animals during their entire lifetime. It is theoretically possible that a poison will precipitate or aggravate a bacterial or metabolic disease just as prolonged inhalation of granite dust promotes tuberculosis. Toxicologists are constantly alert to these possibilities, especially in regard to diseases of unknown origin and diseases of increasing incidence. For example, when it was suggested that DDT is a cause of poliomyelitis (4), the possibility was considered and the lack of evidence was noted. Needless to say, claims for this relationship were dropped, even from scare articles, when vaccines against poliomyelitis were developed.

No matter what the source of suspicion, it is the responsibility of professional toxicologists to explore each possibility. They have done this in the past, and the search will continue indefinitely. However, it is important to realize that there is no conclusive evidence that pesticides - old or new - are a cause of any disease except poisoning.

No discussion of mortality, or morbidity, or storage, or any other effect of chemicals is meaningful except in terms of dosage. The Committee on Pesticides of the American Medical Association (1) has reported that: "Any effects of repeated exposure would appear on the average most promptly, most frequently, most diversely, and most severely among persons whose exposure has been long and intensive." That is why some doubt is associated immediately with any case alleged to result from exposure that is trivial in comparison with what people ordinarily withstand without inconvenience.

Dependable information on tolerable - or intolerable - dosage may be obtained from study of (a) people with occupational exposure, (b) volunteers who agree to take known doses and undergo specified tests, and (c) - in the case of compounds used as drugs - patients treated for some medical condition. A number of pesticides have been studied in occupationally exposed workers, 9 in volunteers, and at least 9 in patients treated therapeutically. I have reviewed the information on dosage in a paper available from the Government Printing Office (9).

Toxicologists must keep in mind the possibility that the clinical effects of one compound may be enhanced by another. Often the degree of this potentiation is low; but Murphy and his co-workers (16) report that it exceeded 100 in animal experiments with malathion and triorthotolyl phosphate, a compound that is not a pesticide. Arterberry and his associates (3) have reported what apparently is the only known instance of a human pesticide poisoning suspected of being aggravated by a drug.

In addition to clinical illness, other effects of pesticides must be recognized. Walker and his associates (22) found DDT in every complete meal they analyzed in this country, but the concentration in the entire diet is so low that the average intake is only 0.184 mg. per man per day. Because DDT is so widely distributed in food, we at the Communicable Disease Center have made numerous studies of this compound and found it occurs also in the fat of almost everyone in the country (7, 11, 15, 19). In the general population, the average storage of DDT is about 5 ppm, and the concentration of all DDT-derived material expressed as DDT is about 12 ppm (11). Meat abstainers (11) and Eskimos (7) store less than the general population. On the contrary, agricultural applicators store about three times as much as the general population (11), and formulators may store more than 600 ppm of DDT and more than 1,000 ppm of DDT-derived material (10). Published results (10) show that men can eat DDT daily at a level approximately 200 times greater than that in the ordinary diet without showing any detectable clinical effect, but of course, they store large amounts of the compound and its derivative, DDE, in their fat tissue. Ortelee (18) found that more than half of the people working for years in DDT-formulating plants excrete, and therefore absorb, DDT at a rate equal to or greater than that of men eating 200 times more DDT than people get from ordinary food. The formulators remained well according to their own evaluation, their work record, and medical examination.

It is a general principle of pharmacology that a steady state of storage is reached in connection with continued, tolerated intake of a drug or other chemical. Thus, after a period of adjustment, the daily excretion of the chemical becomes as great as the daily absorption. Surveys which we carried out in 1954-56 (11) and again in 1961-62 (20) showed that no change had occurred in DDT storage among people in the United States since 1950, when Laug and his co-workers (14) measured it for the first time. It is not known whether the storage of other compounds is at equilibrium, but a group of British scientists (13) and our own group (12) both have found that traces of dieldrin are stored in people without occupational exposure. My associates and I (12) found traces of BHC also. It seems likely that the storage of other stable compounds will be demonstrated as analytical chemical methods are improved.

Production of Pesticides

Because of their value in public health and agriculture, the production of pesticides has increased greatly. The present manufacture of synthetic ones in the United States is about twice as great as the production of all pesticides was in 1949. The development of newer materials has decreased but not eliminated use of older poisons, such as the arsenicals. Use of some of the newer materials, such as DDT, has continued to increase, while the production of other new materials, such as benzene hexachloride, reached a maximum and then decreased somewhat. The new poisons not only are numerous, but all of them of any importance are sold under many trade names. Over 57 thousand formulations are registered in the United States. Furthermore, poisons may be applied in a variety of ways, some of which were unknown only a few years ago. For example, over 6,000,000 acres of cropland in the State of California alone have pesticides applied to them by aircraft each year. I have discussed these and related facts in greater detail in a report published comparatively recently (8).

Injury from Pesticides in Other Countries

In spite of the extensive production of pesticides, they have a relatively good safety record in the United States, Canada, and the

United Kingdom. The record was not so good in some countries of Europe when parathion was permitted for household use. The difference is not necessarily related to technological advancement. Here again, is an example that the way in which a compound is used may be more important than its toxicity in determining danger.

In Japan, Namba (17) found that there were over 3,000 deaths from parathion alone during the 6-year period 1953 to 1958. There is some reason to suspect that the record may be even worse in certain developing countries where vital statistics are collected in only a fragmentary way or not at all. Certainly, there have been isolated reports of hundreds of cases of human poisoning in single outbreaks (6). Good labeling appears to be the most important single measure for promoting safe use by a literate population.

The Contribution of Pesticides to Health

DDT has contributed to the control of at least 27 diseases of man (21). An aggressive campaign against malaria in Greece reduced the number of cases each year from a million in 1938 to twelve hundred in 1958 (2). Many tropical countries with similar needs lack vigorous programs. This is unfortunate, because prevention of disease has not only saved lives, but also permitted economic development and achievement of a higher standard of living (21).

It is a tragic possibility that the safety record of pesticides may be poorest where the need to increase the use of these compounds is greatest. DDT is credited with eradication of malaria in the United States and Italy. But, the greatest threat of malaria has always been in the tropics. Leading agriculturists agree, as pointed out by Decker (5), that people of the United States could not be so well fed without the use of agricultural chemicals, and parathion is credited with eliminating starvation in Japan (17). But the need is more dramatically apparent in some developing countries where partial starvation is a present fact.

When other methods of controlling vector-borne diseases are developed - as they undoubtedly will be - care must be taken to test their safety, as well as their efficacy.

Methods of Improving the Safety Record

If the safety record of pesticides is to be improved, both in the developed and the developing countries, attention must be focused on real problems as determined by official vital statistics, by the reports of poison control centers, and by epidemiological studies. As we have seen, problems may not be identical in different countries.

Furthermore, there must be variation in the ability of different countries to divert technically trained personnel to these studies and related regulatory activities. Therefore, each country must examine its technical resources critically before charting its course.

There are three kinds of laws designed to minimize injury by pesticides: (a) labeling laws, (b) laws regulating residues on food, and (c) laws regulating use. I have given examples of these kinds of laws and reviewed them in a comprehensive paper already cited (8). To be effective, all these laws must be based on research showing that a practice is safe before it can be permitted. Most of the toxicological information required under these laws is based on animal experiments. Often somewhat greater account is taken of use experience in connection with laws that regulate use directly than in connection with the other two kinds of laws.

Without doubt, good labeling is the most important single step to the safe use of chemicals. Good labeling, in itself, will go a long way to promote proper use. If education does not suffice, direct regulation can restrict use of specified chemicals to people who are properly trained and equipped for the work. When necessary, medical supervision of workers may be required, and there are now specific laboratory tests that permit measurement and, therefore, regulation of occupational exposure to many pesticides. In many instances, there are also antidotes and other methods of treatment that can be used with great benefit if poisoning does occur.

Conclusion

The very existence of highly active compounds poses potential and often real problems. Our primary protection is based on the extensive animal experiments required under present law. However, ultimate assurance about human safety of a particular compound must come from study of people with intensive and prolonged exposure. Such studies should give adequate warning of even the slightest danger to people in the general population exposed to traces of the same compounds. Much research remains to be done. The professional toxicologist must stay alert to danger, no matter how remote. But the time has passed when it may be usefully said that little is known about the toxicity of pesticides, or that no legal control of their use exists, or that a wide variety of illnesses from which mankind has suffered for generations are now caused by the newer pesticides.

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THE VALIDITY OF ECOLOGICAL MODELS

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Preface

The paper which I am about to read does not discuss pesticides, but the broader problem that lies back of their use. This is the question raised by the sudden intrusion of scientific technology into the ancient biological system of which man is part. I can hope to touch only upon some properties of this system which have enabled it to persist through geological time--notably the patterns of energy and material flow and the closely knit, generally constructive interrelations within natural communities. These I shall contrast briefly with the current urban and rural picture.

But before proceeding, allow me a few words on the pesticide controversy. Argument by epithet has no place here. Those who have raised the issue in effective fashion have been stigmatized as emotional and impractical, as mere birdwatchers and aesthetes. More recently, in lofty scorn that is intended to close the issue, they are being referred to as "the bugs and bunny crowd."

When it comes to emotion, neither side has a monopoly. Hell may have few furies to match an outraged lover of nature. But one must also agree with a recent remark in Newsweek that there are few things to match money in "exposing a man's heart through his haberdashery."

As to what is practical, the very foundation of the capitalistic system rests upon present self-discipline in the interest of future and permanent benefit. And as to aesthetics, why are great fortunes accumulated through private enterprise so often used to sponsor the creative arts by those who wish to leave permanent memorials to the future?

I may add that derisive name-calling has no standing as a laboratory procedure.

The pursuit of science, like that of the arts, is justified as a creative activity. But its applications can be defended only as they serve the good of mankind. Where scientific knowledge is used without regard to ultimate effects it can be a powerful means of defeating its proper function. This danger is especially great if we neglect those aspects of science which can give us perspective on the world of nature of which we are a part. Such perspective, providing the context within which we operate, is the particular business of ecology.

Viewed thus, the use of pesticides becomes one phase of a larger question: "Are we being thoroughly scientific in our use of science?" Many questions of policy carry heavy emotional overtones. So does this, but they do not concern us here. Conflicts of policy are legitimate and necessary. They are, however, not likely to be fruitful unless the facts are in and science has defined and restricted the issue.

The vigorous public interest which prompts our present discussion comes to focus directly upon the phenomenon of balance in nature. Long used in scientific interpretation, this concept of balance in nature is still a primary one. Modern technological man must continue to be concerned with maintaining the balance of nature, despite his occasional tendency to believe that he has lifted himself to a new plane of existence where the ancient controls upon living organisms no longer apply. And the science of ecology must continue to provide mankind with the perspective from which we can fruitfully study the interrelations of life and environment.

Problems confronting the ecologist involve a variety of complex relationships centering upon living organisms and their needs within restrictive environments. Not only is the individual organism alive, but unique and never precisely repeatable, in spite of its membership in a larger common group. Too, the environment of energy, earth, water, air and living organisms is exceedingly complicated.

Thus the clean experimental controls available to the inorganic chemist handling, say, molecules of sulfur, are not so neatly available to the ecologist. Often, due to human destruction of the natural landscape, he finds himself in the situation of a chemist entering a laboratory of broken apparatus and empty reagent bottles, save that the matériel of the chemist is replaceable.

Many precise quantitative techniques are of course available to the ecologist and used by him, but the very nature of his problems requires him to go beyond such tools to find his answers. The problems of biology arise in living nature. Wherever they may lead us, we hope to be able to return there to deal in more enlightened fashion with living nature when we have found even tentative answers to these problems.

The primary concern of the ecologist is with pattern and process in living nature. What the ecologist sees "in the field" of nature then is the background against which he asks disciplined questions. One of the primary questions may, for example, be, as James Bonner puts it, "Who eats whom and why?" There need be no limit to the refinement to which the ecologist may be driven in search of answers to this and other questions. The importance of his quest is not a function of the precision of the means needed to obtain his answer. Rather it lies in the judgment with which he asks a truly sensible question to begin with. The intrinsic quality of this or any other scientific investigation is to be measured, not by the intricacy and cost of the apparatus employed, but by the effectiveness of the final answer that results.

By this standard the work of the ecologist measures up to strict scientific standards and in particular affords useful, even indispensable, guidance in human affairs. To begin with, he works within a framework of known phenomena developed by others. Included here is the unique fitness of our planet to sustain life as we know it. Again, there is the five billion-year antiquity of the earth, the one million-year newness of its dominant species, Man. There is further the tremendously accelerating power of human technology as a geological and biological force. This power is to be viewed against an inexorable background--the finite extent of the habitable earth, the uncompromising operation of those rules that appear to govern the transformations of energy and substance, and the long record of natural selection. Man did not appear until conditions, inorganic and organic, were suitable for so remarkable an innovation. And we know that thereafter he has often, by increase in numbers and power, impaired or even destroyed the potential of his environment.

These are matters of ecological knowledge. That science has two traditional phases: the ecology of the individual, autecology, and that of the community, synecology. Autecology--actually that of the species and its variants--deals with requirements, limitations and the way these relate to the ambient environment. Two ideas in particular have emerged here, those of <u>niche</u> and <u>role</u>. A niche is an opening or opportunity for the entrance and survival of an organism. A role is what its name implies, the part played in an ecosystem by one of its living components.

Both niche and role play active parts in natural selection. As niches have developed through environmental change, organisms have competed to enter them. Once a species is established within its niche, competition is largely with its own kind. The case of Man is a special one. His flexible behavior has enabled him both to occupy and create niches without physical change on his part. He had entered and spread over every continent long before the dawn of history. Once established, his increase made possible organization and a diversity of roles favorable to the group. This was especially important after his invention of agriculture.

In nature the role of an organism must be favorable, or at worst not destructive to the community. Otherwise, like a completely efficient parasite, the organism will destroy its own niche. In human society, numbers may increase beyond the number of effective roles. Unemployment is a common symptom, followed in the past by the familiar Malthusian checks. Incidentally Malthus was by no means the first to identify their operation, as one may confirm by reading Samuel II, 24. Here King David, faced with a startling increase among his people, is forced to choose whether he will accept war, famine or pestilence as a remedy.

The classic niche favoring a powerful human culture is the presence of a fertile nutrient area such as the Roman Plain or the Basin of Mexico. The corresponding role is one of effective land use and management. At first the resulting increase in numbers is likely to favor efficiency, as we have said. Eventually, unless population is stabilized, it exerts more pressure upon the nutrient base than can be met. Often cultural breakdown, leading to mismanagement, hastens decline. Famine and wars of expansion have been familiar results. Or, as elsewhere in nature, the crowding of a single species has made it vulnerable to epidemic.

We have ample laboratory and field experience with other organisms to give us models of this process, as for example in Thomas Park's work with flour beetles or the familiar examples of deer and elk too well protected in national parks and forests. It is the invariable rule of experience that no species has ever been observed to multiply indefinitely. In the end it must come to terms with the limitations of its habitat, no matter how favorable this may once have been. The implications for our own species are plain enough. Fortunately they are now being discussed with more freedom and concern than ever before.

Older cultures of the Orient and Near East have been overpopulated for centuries. Here the issue is clear. In the United States it is still confused. We have a surplus of food and some four acres of agricultural land per capita, in contrast to scarcity in many other lands. Here the prospect of hunger appears remote, even in theory. This leads us to overlook the immediate issue which is not physical survival but the effect of crowding upon the quality of existence. For whenever numbers come to exceed the needs of organization and function they lead to a progressive loss of individual freedom.

We already have two traffic jams a day in many places. The rising costs of public services in congested centers are recorded in tax assessments and ripple out into the surrounding country. The classical economic studies of Joseph Spengler show that after a city reaches its optimum size further growth becomes liability instead of asset. This, of course, runs counter to commercial rejoicing over the baby crop and the traditional promoter's slogan "The bigger the better."

More fundamentally, a physical principle is involved. When dynamic particles, of whatever sort, are confined within a finite space, continuing increase in numbers is accompanied by a decrease of mean free path. This is as true of a California freeway as of a flask of gas molecules. Further, when energy is added to the system, as it has been by the use of fossil fuel in internal combustion engines, there is further loss of freedom, no matter how skillfully we guide the moving units.

But it is in the dynamic structure of natural communities that we find our most comprehensive model. Our evidence here is far from complete, but what it lacks in this respect is made up by its consistency. Wherever the development and operation of biotic communities have been observed the answers are the same. From simple, often uniform beginnings, controlled by physical factors, communities move in the direction of greater complexity and organization, with an increasing number of niches and roles, and towards a state of dynamic equilibrium. Available materials and the current input of energy are used to maintain the system in working condition. We call this the balance of nature. In terms of physical science it represents an open steady state.

As the community moves toward this condition it modifies the raw physical environment and exerts increasing control within the ecosystem. Thus it favors an optimum capacity of its environment to sustain life. The living cover impounds and distributes solar energy, retarding the increase of entropy. It likewise slows the return of water to the sea, giving it greater opportunity to be used by land organisms and cushioning the surface against erosive wear. Meanwhile the tightening nutrient web of green plants and fungi, vertebrate and invertebrate animals promotes the efficient use and recycling of materials.

A residual effect of this process is the formation of soil. Natural soil is a familiar measure of the capacity of an environment. It is evidence of a system that has been biologically constructive as well as self-sustaining. It is of the utmost importance for us to note that natural communities operate on a current budget of solar energy, accumulating capital from it in the form of reserve potential. At times in earth history there have been unusual storages of carbon compounds in the form of coal, oil and gas as expressions of such capital, now being drawn upon at rates far exceeding those of its accumulation. In addition our economy has largely grown by the destruction of natural communities which used their supply of energy in constructive fashion.

The question then becomes "to what extent has man substituted equivalent systems?" To seek an answer let us examine the current patterns of use in both rural and urban areas. We are giving urban uses high priority over rural, regardless of potential for the production of organic material, to say nothing of other values. This applies not only to space for urban dwelling and industry, but to the growing network of lava-like highways. Such replacement of rural land use now exceeds a million acres a year. Yet cities remain dependent upon rural food and fiber production. They also require increasing amounts of water, while they themselves are essentially waterproof, so that they must reach ever farther into rural areas to supply this necessity.

Unlike natural communities they seldom recycle the materials they use, but dispose of wastes into air and water. Often these are in such form that they are no longer usable, if not harmful. The solar energy that falls upon a city is transformed to heat, instead of being impounded by green plants for further use. One result is an increasing demand upon the supply of water and energy to maintain living comfort during the hot season.

If we view the landscape as an organic entity, sound equilibrium would require urban concentrations to compensate for the pressure they exert upon rural areas. Otherwise they would be parasitic. In many ways they do return the debt. They exchange services, manufactured goods, capital, cultural advantages and administration for rural products. Since much greater profit comes from the processing and distribution of raw materials than from their production, the exchange seldom favors the rural producer. Increasingly he is obliged to adopt mass production techniques similar to those employed in industry.

Such mass production makes the farm areas more dependent than ever upon the cities, not only for outlet, but for machinery, chemicals, capital, even management, and in the end for subsidy. As a result farms, like commerce and industry, become fewer, larger and more specialized. The old self-sustaining family farm, like the corner store, finds it difficult to survive. Increasingly we hear that the farm problem can be solved simply by getting rid of small farms, getting farmers off the land and into the city. What will happen to them there is not discussed in this context.

Meanwhile urban industry has developed such facility in producing consumers' goods that it must make increasing efforts to promote consumer demand. Machinery design, for example, is concentrated upon the real or supposed needs of the large mass-production farm. The small operator is thus under pressure to buy more elaborate and costly equipment than his project needs or can support. That this is not necessary is proved by the experience of Japan and Denmark, where mechanization is suited, in cost and function, to smaller units.

What of the farm itself as a biological system? Is it tending toward a pattern of diversity and interdependence, of cumulative long-range build-up in place of increasing potential in the use of energy and materials that we observe in the natural community? Instead of this, we find that a very different system is developing. Fields, so far as possible, are divested of life and then seeded with a single organism, adding from extraneous sources whatever is thought necessary to it. The model here comes from the laboratory of microbiology, not from nature. Precise human controls are used to sterilize and inoculate.

Increasingly research, guided by economic policy, has been weighted in favor of such a system. We have only glimpses of its eventual effects, or of possible alternative methods. We do know that studies of the biological control of sugar cane pests which I heard about half a century ago have borne fruit in Hawaii. Unsprayed plantations now show better results than those in which all insects have been held in check by spraying. The late Warren Thornthwaite called my attention to the increasing compaction of farm soils by heavy machinery. And the forcing of high yields of special crops by artificial aids--maize and pineapple for instance--has at times been at the cost of soil structure and permanent fertility.

Our aversion to hedgerows, patches of natural vegetation, bird and other animal life as an integral part of farm operation is not based upon fundamental research. During the drouth of the 1930's I learned of instances in three different states where the only forage available was from patches of native grassland that had, by some chance, been allowed to survive. And I have just learned of an association of ranchers in Colorado organized to prevent the extermination of so-called predators on their property.

Meanwhile official studies of the benefits of composting and other techniques for the recycling of organic materials have lagged. Their merits are largely left to the promotion of cultists, unable or unwilling to put their claims to rigid scientific tests. Meanwhile, too, public policy seems fairly described by an administrator who said "We are so heavily committed to the study of artificial aids to production that we have become afraid to stick our necks out." In short, I have seen little in the modern rural-urban landscape to compare with the metabolic pattern of flow of energy and materials in natural communities.

What I am saying is not meant to disparage all of the remarkable research, public and industrial, that has been devoted to improving both rural and urban activity. My only concern is that too little of it has gone into the matter of fundamental and controlling patterns, to permanence and health of the living landscape. I should like to see us be truly scientific in our application of science, using it for context as well as detail. Medicine lagged so long as its chief concern was with symptoms. Its advance began with study of normal anatomy and physiology. The greatest progress in social science has not come from an examination of social ills, but rather from concern with normal cultural process. I believe that scientists concerned with use and management of the landscape should heed these examples.

Now long ago I visited a farm of less than 200 acres, almost completely self-contained. There I saw a fine garden, full cupboards and freezer, a cold spring and a comfortable house, attractive and convenient. There was also a small dairy herd, spotless barn and milk-house. But the herd was being given up because of official demand that a costly stainless steel tank be installed. Recently an inspector, seeing a single deposit of manure some distance out from the milking shed growled "You'll have to get rid of this sort of thing if you want to stay in business." On being reminded by the farmer that the cows in a large commercial dairy not far away were wading ankle-deep in manure, he brushed this aside by saying "That's different. That is big business." I should add that the elderly farm wife whose husband presided over this archaic pattern of diversity and balance said as we left "We have had a good life."

To sum up, my own interest in the care and management of natural resources has been the result of ecological experience. To one with this background the evidence of depleted land potential is widespread and distressing. But I early came to realize that a negative approach, like the preoccupation of ancient physicians with disease rather than health, was fruitless. Increasingly since then I have interested myself in examples of sound resources management.

They are to be found in the general economy of Switzerland and Denmark; among the Amish and Mennonites and among the Norwegian Lutherans at Cranfill's Gap in Texas. They are exemplified in the sustained yield operations of the best of the lumber corporations as well as in the mixed farm and forest economy of Indians in western Guatemala. Increasingly they appear in game management techniques and in fish and water management in the Tennessee Valley.

All are alike in working for balance among diversity of means. All exhibit caution and economy in the use of energy and materials. Consciously or not, all have a common pattern. It is not the fashionable one of an ever widening economic spiral, but rather that of the model placed before us in the dynamics of natural communities.

Ecological models do exist. Their nature and meaning is clear. The burden of proof rests upon those who assert that man's economy can safely disregard them.

SUMMARY REMARKS

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The time has come when we must close this most interesting and profitable discussion. Though we close the discussion here this evening, it will not be closed in the halls and the corridors of this meeting, nor in the public forum of the world.

First, I wish to thank the speakers on the panel for the excellent presentations which they have made and I wish to thank the audience for the keen and penetrating questions which they have posed to the members of the panel.

I shall not attempt to summarize what has been said this evening. Each of us must do that for himself. However, I should like to remind the biologists present that the citizenry of the world properly looks to the biologist for guidance in this important matter.

As members of the human race we are entitled to have and to express our own value judgments as to the relative importance of various items. The values, which man lives by, determine the course of our civilization. Certainly each of us has not only the right but the responsibility to participate in the development and maintenance of values which we believe to be important.

However, as scientists we have a responsibility equally great, namely that of soundly interpreting the factual data which are available and of refusing to draw conclusions when factual data are not available to justify the development of a sound conclusion.

To the biologists here assembled may I express my confidence that they will provide the necessary leadership, collect the data which are needed, carefully analyze all the factors involved, and present a sound solution for this presently vexing problem.

To those in the audience who are not scientists, may I give assurance that the present sound and fury of controversy is not a prelude to the doom of our civilization.

The development of civilization cannot stand still. Ways and means must be found which will safeguard man's basic interests, including his health and his environment, and which, at the same time, will encourage that continued relentless search for and application of knowledge which brings betterment to our lives, betterment to the lives of all the people throughout the world.